

- Atmospheric Infrared Sounder (AIRS)
- Advanced Microwave Sounding Unit (AMSU)
- Humidity Sounder from Brazil (HSB)
- Aqua Spacecraft

*Improving Weather and Climate Prediction*

The 7<sup>th</sup> International Workshop on  
Greenhouse Gas Measurements from Space

## AIRS multilevel retrieval of Atmospheric CO<sub>2</sub>

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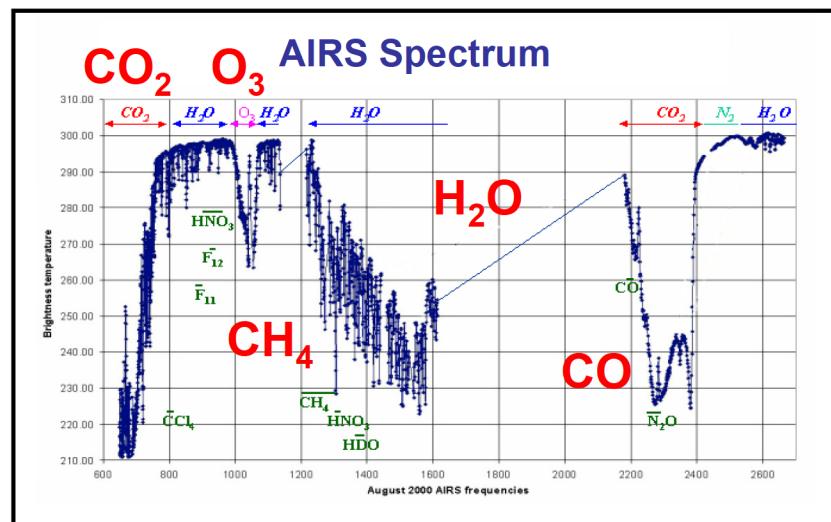
# The Atmospheric Infrared Sounder on NASA's EOS Aqua Spacecraft

- AIRS Characteristics
- Launched: May 4, 2002, Aqua S/C
- Orbit: 705 km, 1:30pm, Sun Synch
- IFOV :  $1.1^\circ \times 0.6^\circ$   
(13.5 km x 7.4 km)
- Scan Range:  $\pm 49.5^\circ$
- Full Aperture OBC Blackbody,  $\varepsilon > 0.998$
- Full Aperture Space View
- Solid State Grating Spectrometer
  - IR Spectral Range:  
 $3.74\text{-}4.61 \mu\text{m}$ ,  $6.2\text{-}8.22 \mu\text{m}$ ,  
 $8.8\text{-}15.4 \mu\text{m}$
  - IR Spectral Resolution:  
 $\approx 1200 (\lambda/\Delta\lambda)$
  - # IR Channels: 2378 IR
- VIS Channels: 4
- Mass: 177Kg,  
Power: 256 Watts,  
Life: 5 years (7 years goal)

AIRS



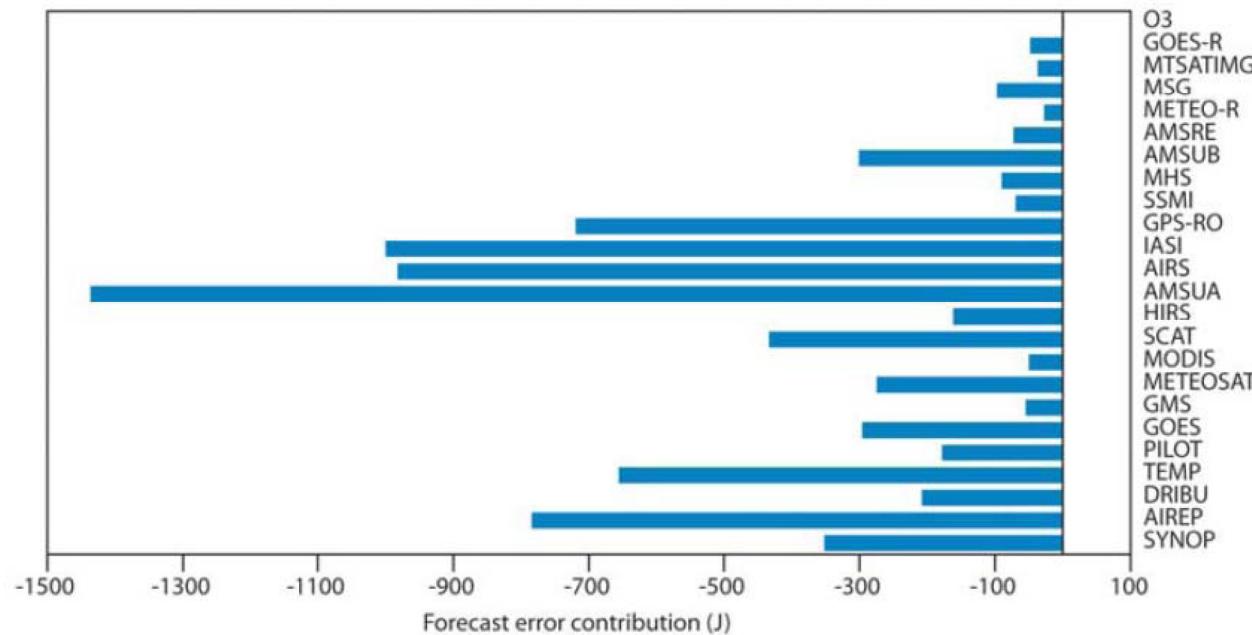
CO<sub>2</sub> O<sub>3</sub> AIRS Spectrum





# ECMWF Finds High Infrared Sounder Impact

- Microwave satellite measurements (AMSU-A) are responsible for 18% of the forecast error reduction
- Infrared measurements (AIRS and IASI) for 12% each
- 10% of error reduction is due to radio occultation



From Cardinali (ECMWF Tech. Memo. 599, 2009), See also, Cardinali, C, Monitoring the observation impact on the short-range forecast, Q. J. R. Meteorol. Soc. 135: 239–250 (2009)

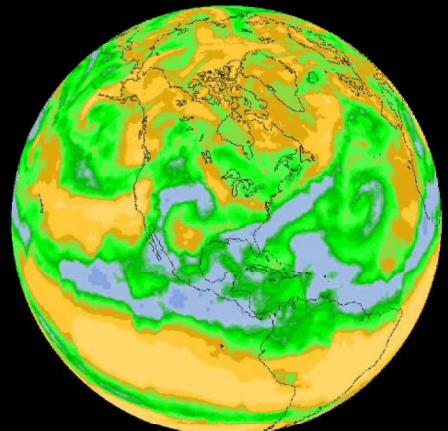


National Aeronautics and  
Space Administration  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California

## AIRS Greenhouse Gases

H<sub>2</sub>O

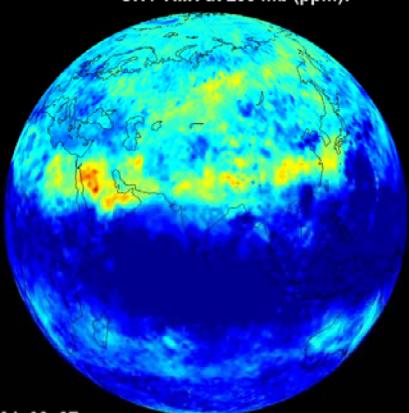
500 mb Water Vapor (g/kg dry air)



2005.08.01

CH<sub>4</sub>

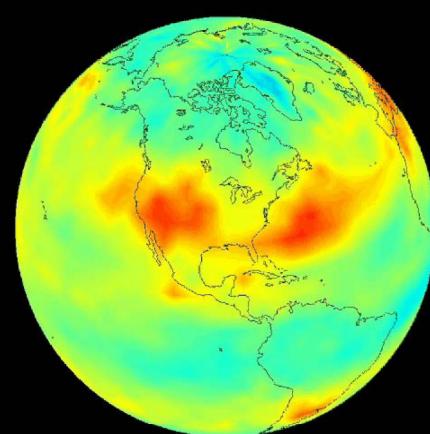
CH4 VMR at 200 mb (ppm):



2004\_08\_27

CO<sub>2</sub>

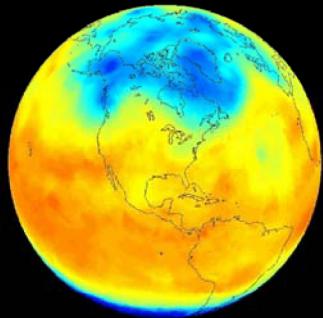
Mid-Tropospheric CO<sub>2</sub> (ppm)



## Other AIRS Atmospheric Climate Products

Pagano, JPL, 2009

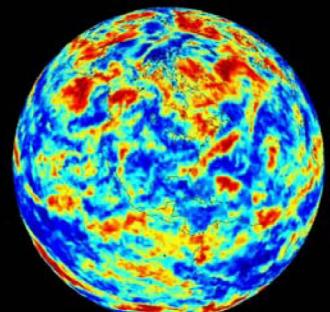
500 mb Temperature (K)



2005.08.01

Temperature

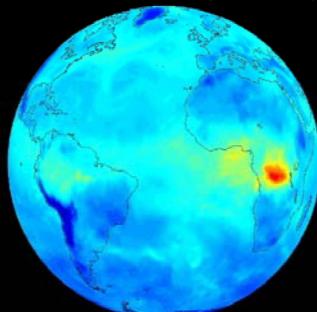
Cloud Fraction



2005.08.01

Clouds

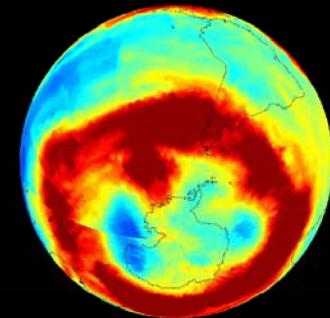
Total Column CO (molecules/cm<sup>2</sup>)



5.08.01

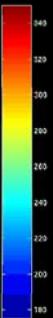
CO

Total Column Ozone (DU)



01

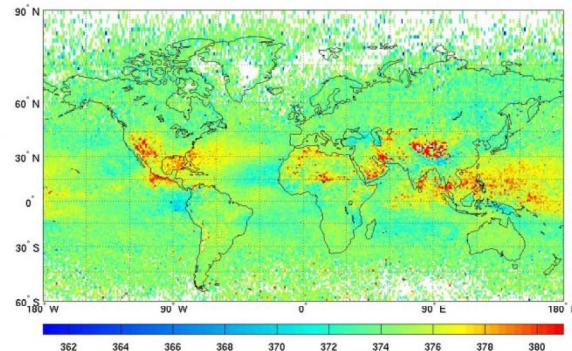
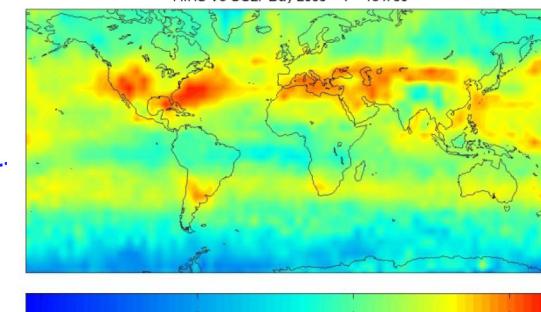
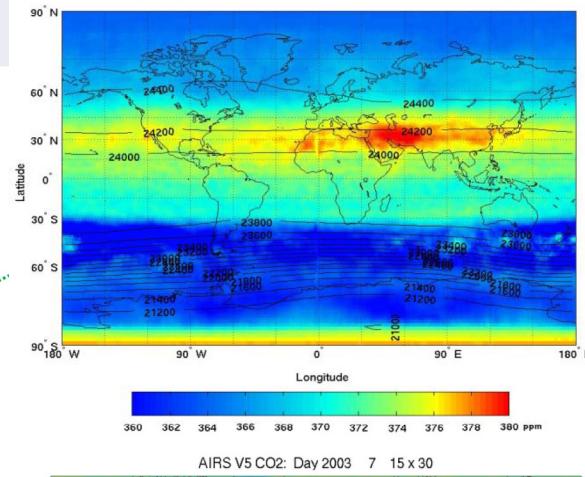
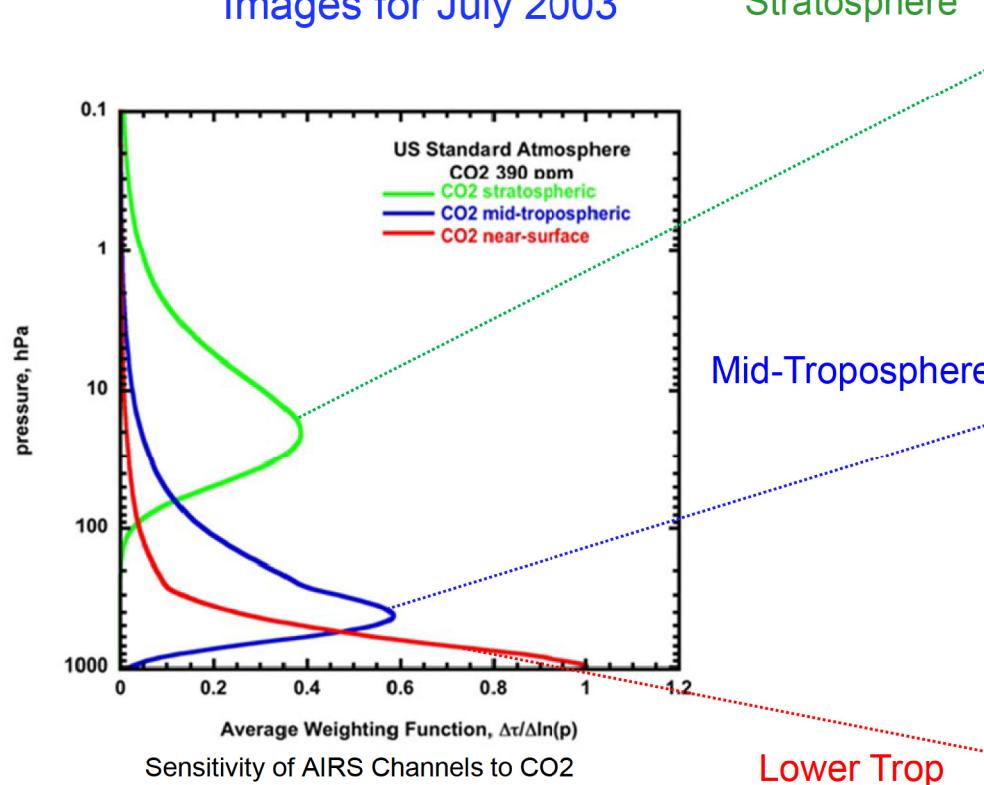
O<sub>3</sub>





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## 3 Layers of CO<sub>2</sub> Derived from AIRS by Dr. Chahine, and Colleagues, 2011 Images for July 2003

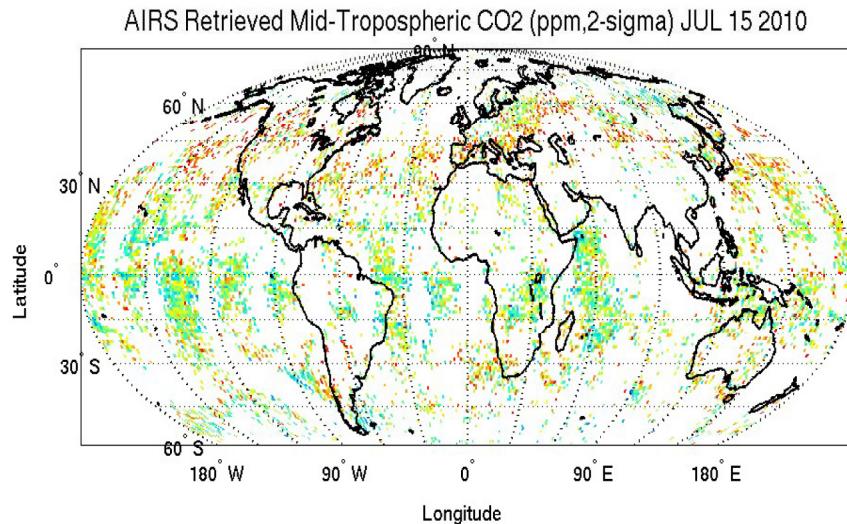




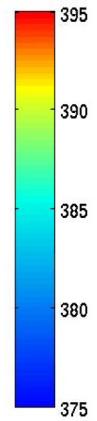
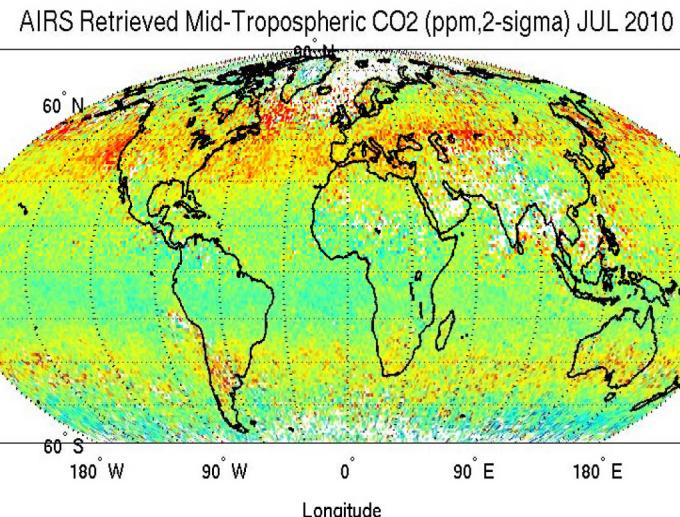
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# Global Yield of AIRS Level 2 Mid-Tropospheric CO<sub>2</sub>

AIRS Daily CO<sub>2</sub> Yield  
1°x1° Spatial Resolution



AIRS Monthly CO<sub>2</sub> Yield  
1°x1° Spatial Resolution



Day/Night, Pole-to-Pole, Land/Ocean/Ice, Cloudy/Clear

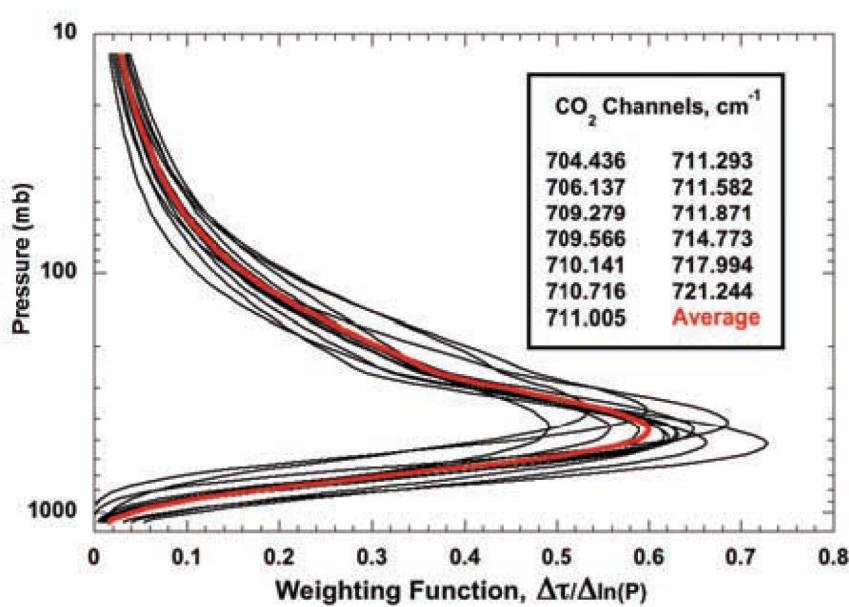
AIRS CO<sub>2</sub> Data Products Released (2002 to present)  
[http://airs.jpl.nasa.gov/AIRS\\_CO2\\_Data](http://airs.jpl.nasa.gov/AIRS_CO2_Data)



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## How we retrieve CO<sub>2</sub>...

1. Pick Channels Most Sensitive to CO<sub>2</sub> and Least Sensitive to Other Variables



Chahine, M., C. Barnet, E. T. Olsen, L. Chen, and E. Maddy (2005), On the determination of atmospheric minor gases by the method of vanishing partial derivatives with application to CO<sub>2</sub>, Geophys. Res. Lett., 32, L22803, doi:10.1029/2005GL02416

2. Employ Radiative Transfer Algorithm

$$R(\nu) = S_s(\nu, \varepsilon_s, \dots) + \int_{p_s}^0 B[\nu, T(p)] \left( \frac{\partial \tau(\nu, p, \dots)}{\partial p} \right) dp$$

3. Define Cost Function: Obs - Calc

$$G^{(n)} = \sum_{\nu} \left[ F^{(n)}(\nu) \right]^2 = \sum_{\nu} \left[ \Theta_M(\nu) - \Theta_C^{(n)}(\nu) \right]^2$$

4. Employ Gauss Minimization Method  
X<sub>i</sub> 's are T, H<sub>2</sub>O, O<sub>3</sub> and CO<sub>2</sub>

$$dG = \frac{\partial G}{\partial X_1} dX_1 + \frac{\partial G}{\partial X_2} dX_2 + \dots + \frac{\partial G}{\partial X_i} dX_i + \varepsilon.$$

5. Partial Derivatives Vanish when Minimized

$$\frac{\partial G}{\partial X_1}, \frac{\partial G}{\partial X_2}, \frac{\partial G}{\partial X_3}, \dots, \frac{\partial G}{\partial X_i} = 0$$



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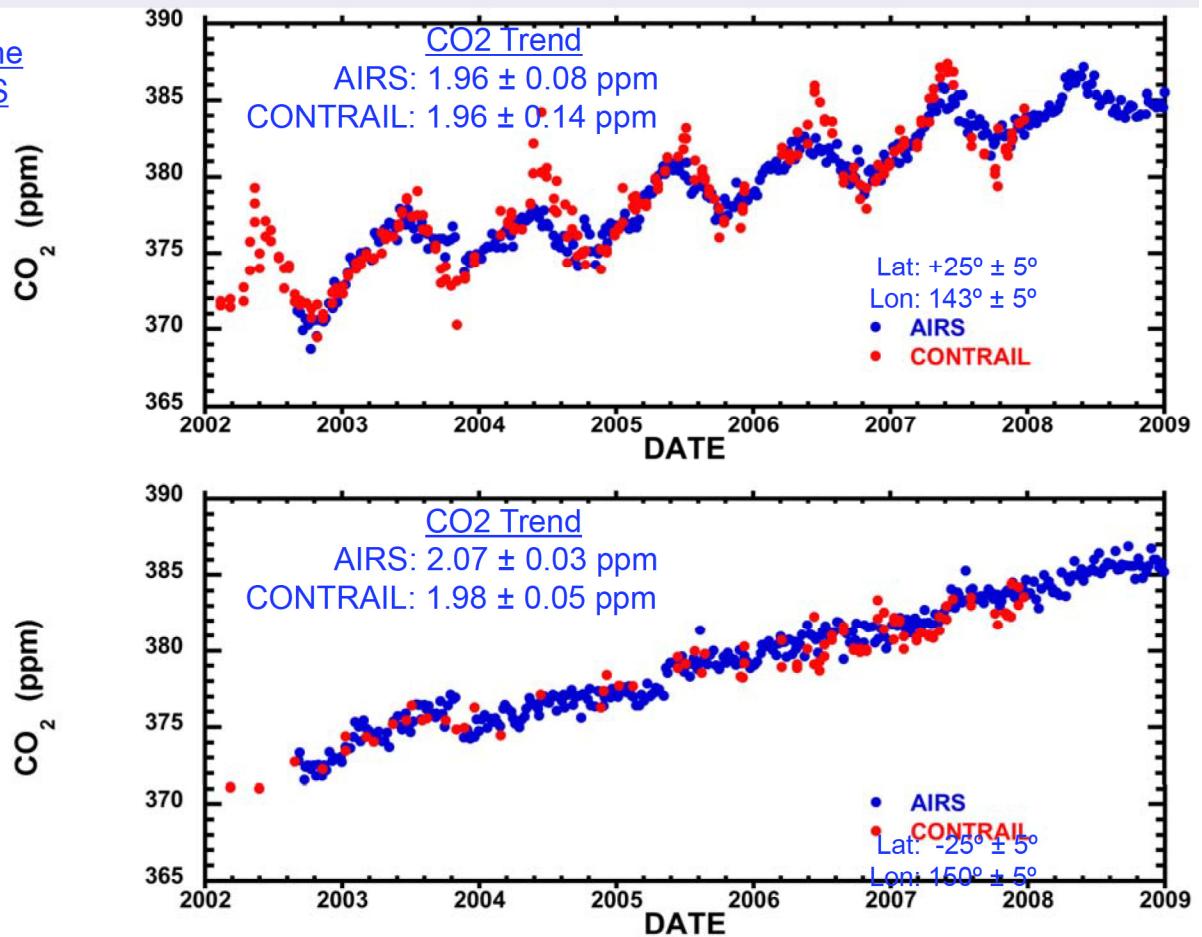
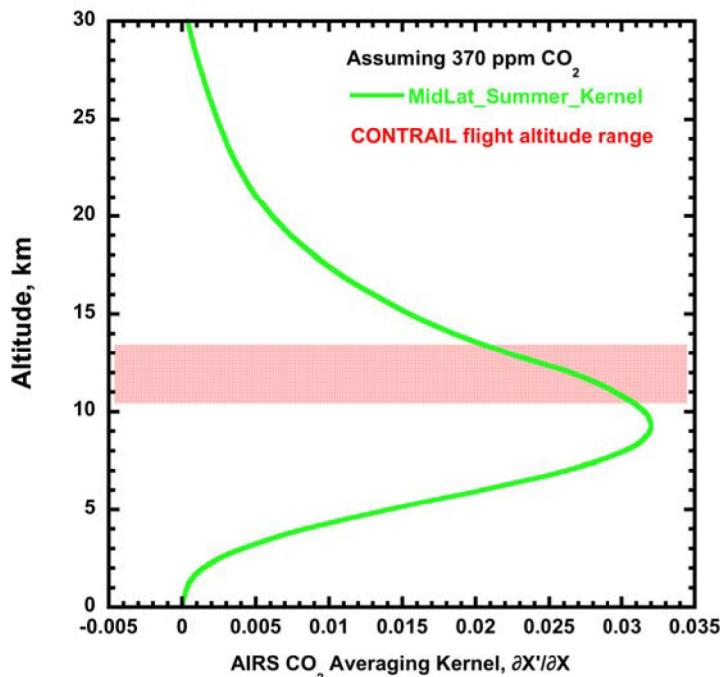
# Time Series for AIRS CO<sub>2</sub> and CONTRAIL Aircraft Data

(in 10°x10° boxes at extremes of latitude for cruising altitude)

AIRS Data are 7-day averages; CONTRAIL data are individual measurements

CONTRAIL Measurements provide long timeline  
and good latitude coverage near peak of AIRS  
averaging Kernel

- CONTRAIL flights over ocean between Sidney and Tokyo:
  - Cruising Altitude: 10.5 – 12.5 km
  - Pressure Range: 240 to 180 hPa
  - Latitude Range: 30°S to 30°N
  - Longitude Range: 135°W to 153°W



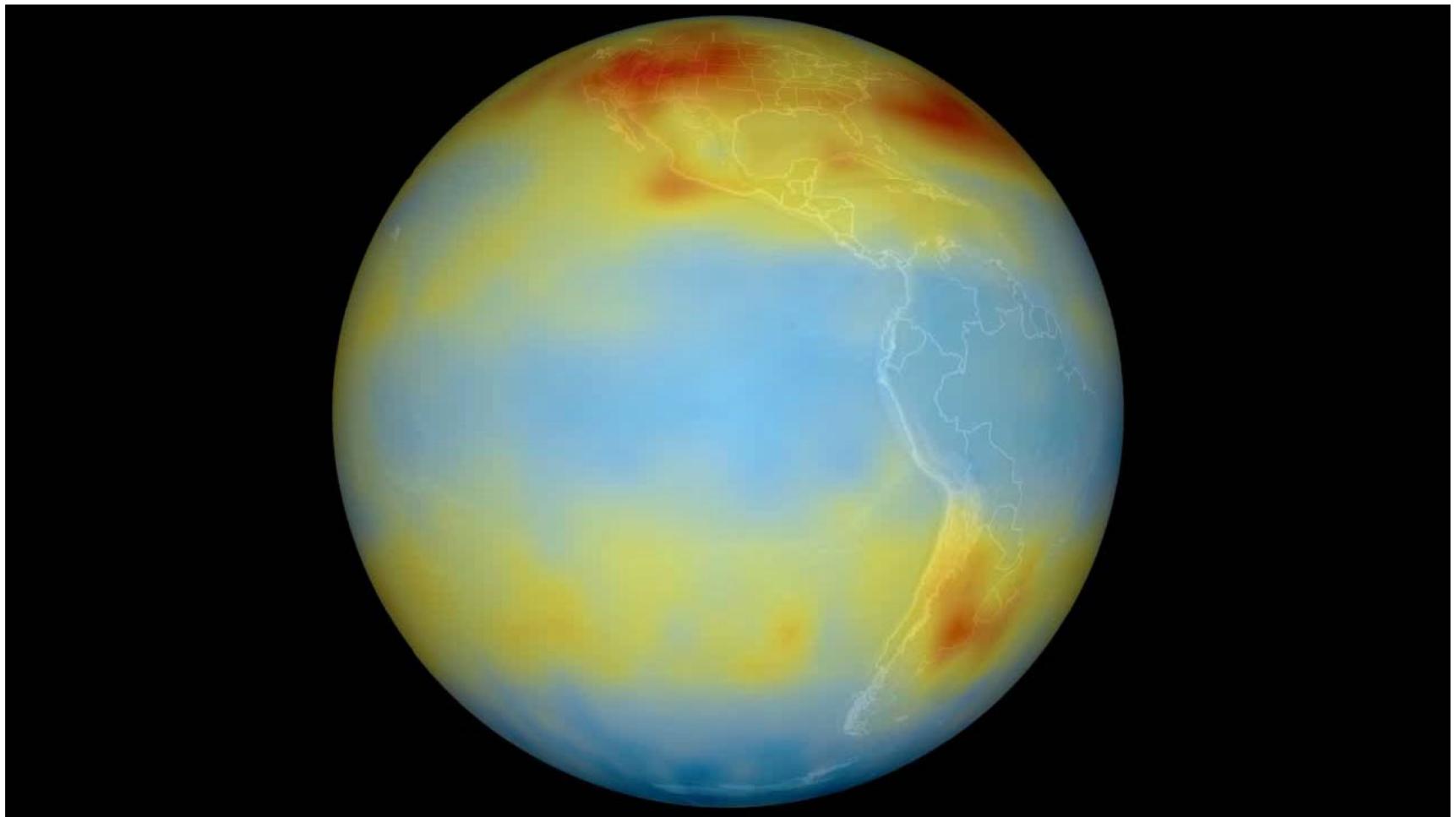
CONTRAIL Data courtesy of T. Machida, via World Data Centre for Greenhouse Gases <http://gaw.kishou.go.jp>

See also: Chahine, M. T., L. Chen, P. Dimotakis, X. Jiang, Q. Li, E. T. Olsen, T. Pagano, J. Randerson, and Y. L. Yung (2008), Satellite remote sounding of mid-tropospheric CO<sub>2</sub>, Geophys. Res. Lett., 35, L17807, doi:10.1029/2008GL035022



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## CO<sub>2</sub> Belt in SH Mid-Troposphere (5-8 km)



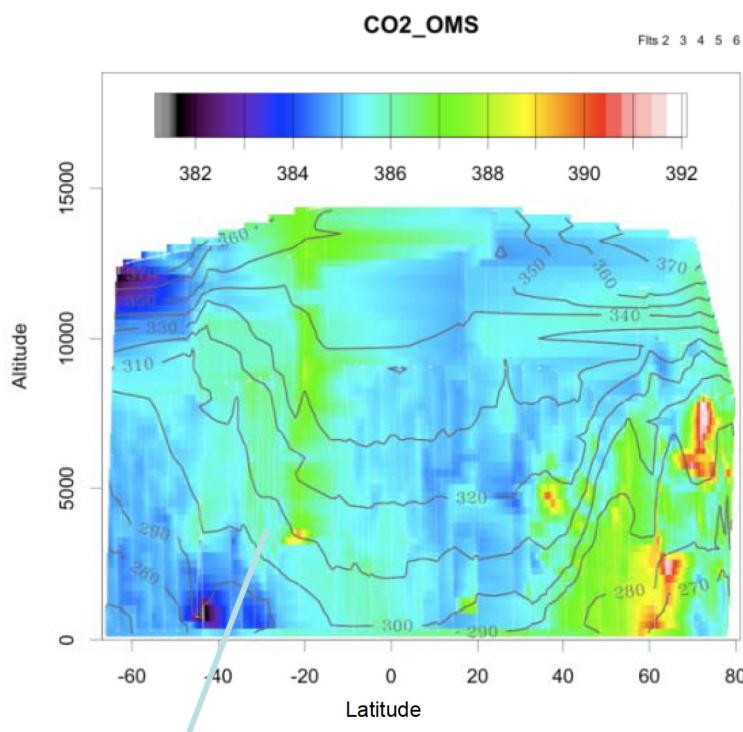
Animation Courtesy of Lori Perkins, GSFC, SVS



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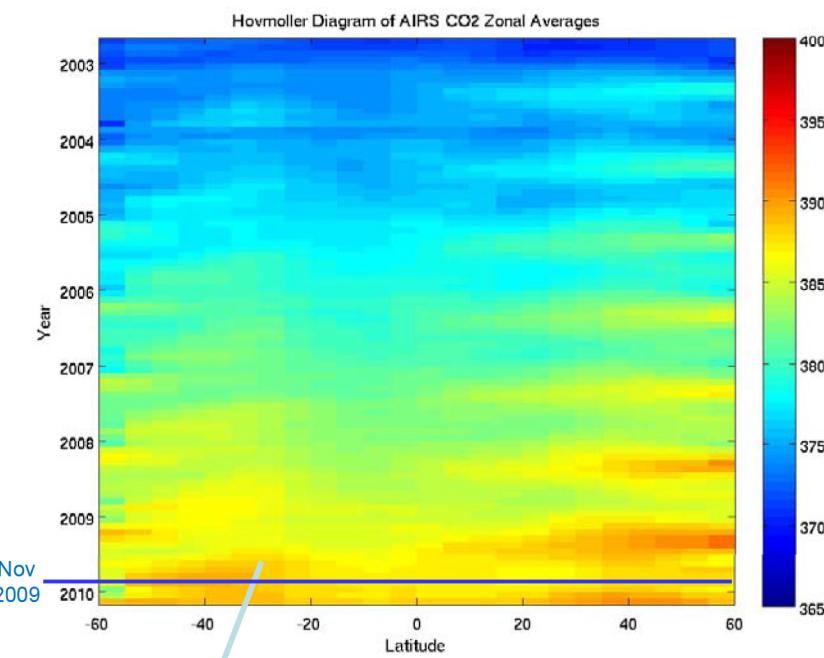
# First Major Discovery: CO<sub>2</sub> is not well mixed in Mid-Troposphere. CO<sub>2</sub> Belt.

HIPPO Campaign -2009  
Steve Wofsy (Harvard)



Belt of CO<sub>2</sub> in SH (Nov, 2009)

Hövmoller Diagram of AIRS  
Observed Mid-Tropospheric CO<sub>2</sub>

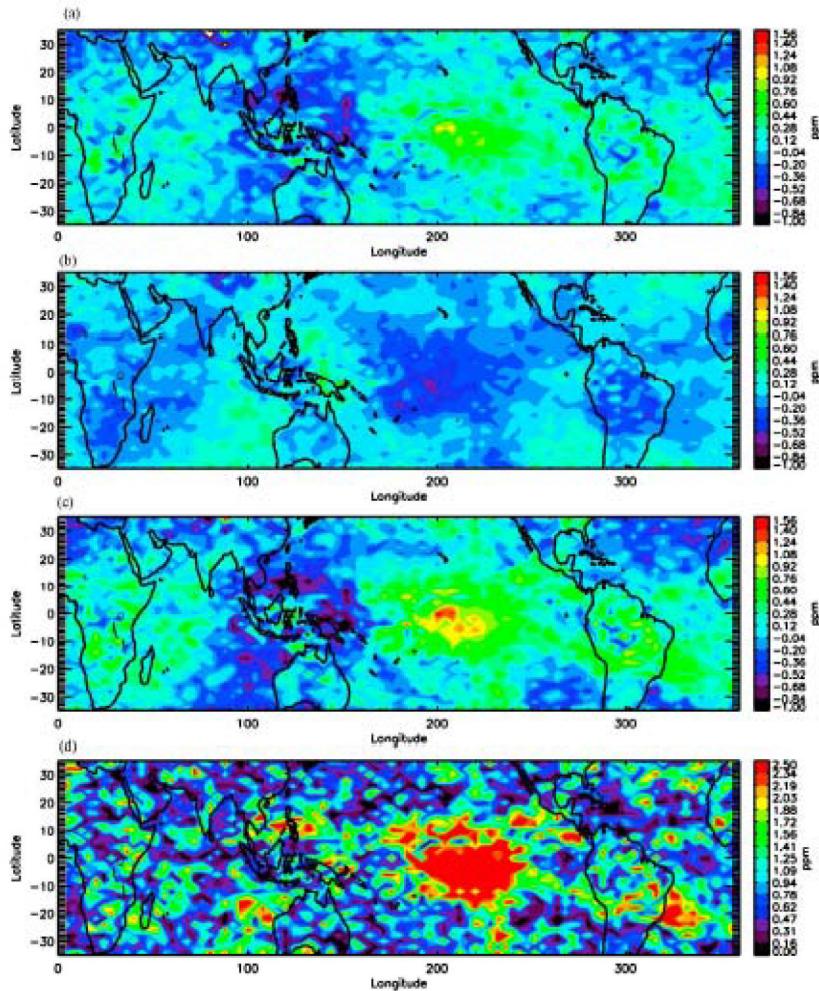


Belt of CO<sub>2</sub> in SH



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# UofH/JPL Study Finds Influences of El Niño in Mid-Trop CO<sub>2</sub> Levels observed by AIRS



**Figure 1.** (a) AIRS detrended and deseasonalized CO<sub>2</sub> averaged for 11 El Niño months, (b) AIRS detrended and deseasonalized CO<sub>2</sub> averaged for 17 La Niña months, (c) AIRS CO<sub>2</sub> difference between El Niño and La Niña events, and (d) t-value for the CO<sub>2</sub> difference.

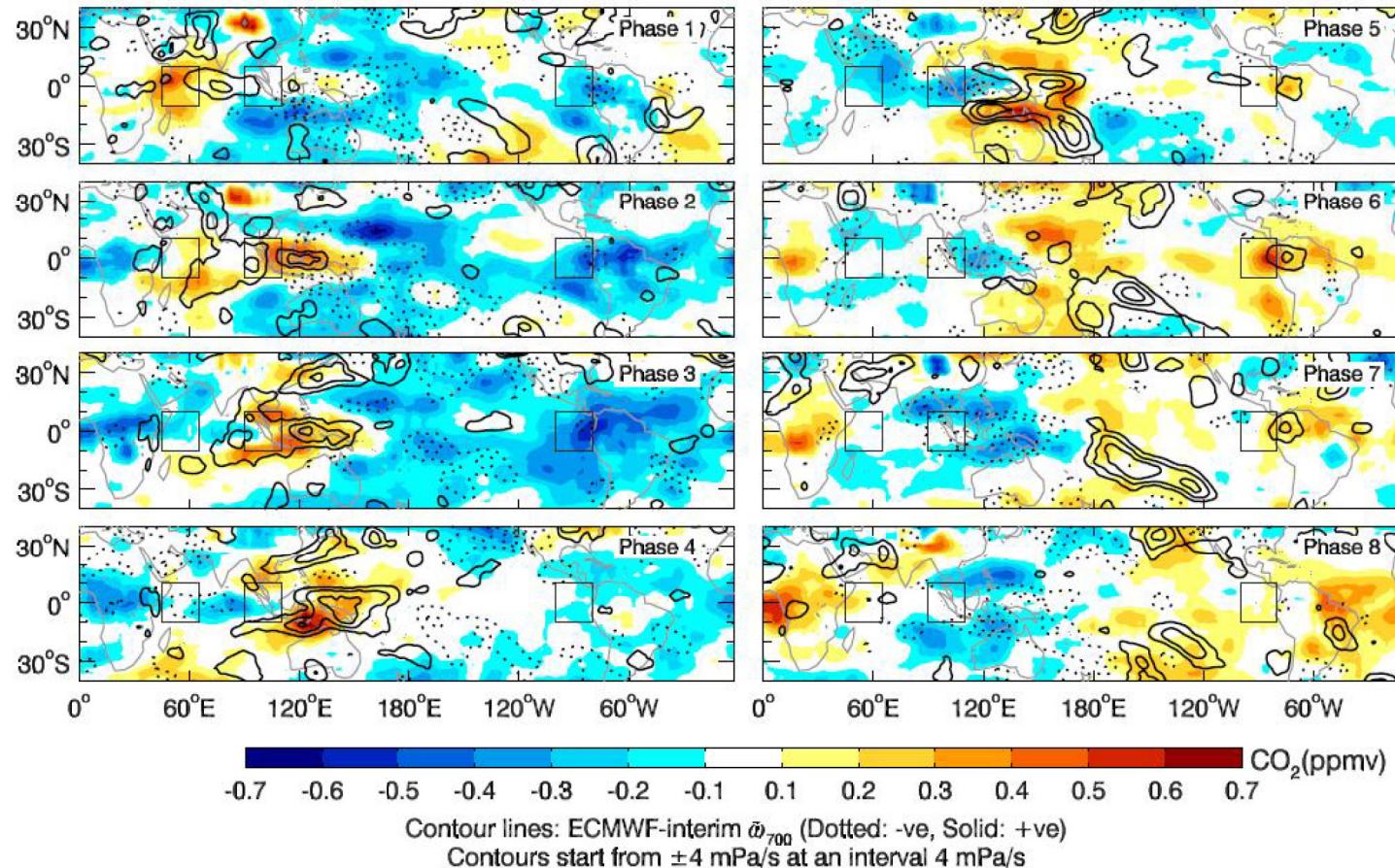
- Analysis suggests that the influences of El Niño events and polar vortex on the CO<sub>2</sub> concentration are apparent in the AIRS data.
- During El Niño, mid-tropospheric CO<sub>2</sub> is enhanced in central Pacific Ocean and diminished in the western Pacific Ocean.
- In the polar region, mid-tropospheric CO<sub>2</sub> is diminished if the polar vortex is strong. Polar mid-tropospheric CO<sub>2</sub> is enhanced if the polar vortex is weak.

Jiang, X., M. T. Chahine, E. T. Olsen, L. L. Chen, and Y. L. Yung (2010), Interannual variability of mid-tropospheric CO<sub>2</sub> from Atmospheric Infrared Sounder, Geophys. Res. Lett., 37, L13801, doi:10.1029/2010GL042823



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# MJO in AIRS Carbon Dioxide; Correlates with ECMWF Vertical Velocities



Li, K. F., B. Tian, D. E. Waliser, Y. L. Yung (2010), Tropical mid-tropospheric CO<sub>2</sub> variability driven by the Madden-Julian oscillation, *PNAS*, 107 (45), 19171-19175, doi:10.1073/pnas.1008222107.

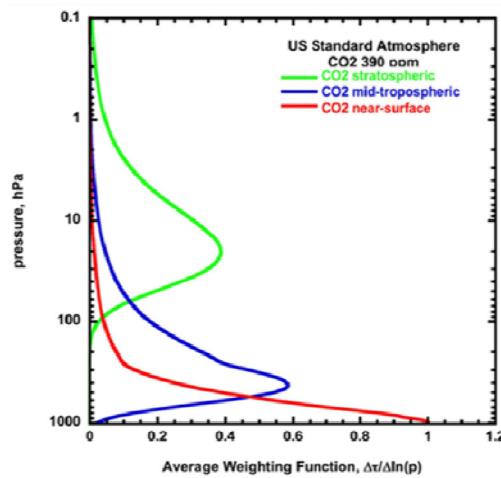
12  
12



## Factors Affecting the CO<sub>2</sub> Retrievals

ν range:	Mid-Troposphere - 10km	Stratosphere – 30km	Lower Trop – 2.2km
	13 CO <sub>2</sub> channels: 700 cm <sup>-1</sup> – 722 cm <sup>-1</sup>	17 CO <sub>2</sub> channels: 650 cm <sup>-1</sup> – 680 cm <sup>-1</sup>	10 CO <sub>2</sub> channels: 730 cm <sup>-1</sup> – 745 cm <sup>-1</sup>
T(p)	Strong	Very strong	Strong
O <sub>3</sub>	Strong	Weak	Medium
H <sub>2</sub> O	Medium	No impact	Medium
Surface emission, E <sub>s</sub> (T <sub>s</sub> , ε <sub>s</sub> )	Very weak	No impact	Medium

$*(\Delta G/\Delta \text{CO}_2)$  describes the sensitivity of observed spectra to changes in CO<sub>2</sub>. It is a function of the lapse rate of atmospheric temperature profiles which is 7 K/km in the mid-troposphere, 1.5K/km in the stratosphere and 10K/km near surface.



- Mid-troposphere: Operational and Released to the Public (Sept 2002 – Present)
- Stratosphere: Algorithm Completed, QA and Validation Underway
- Lower troposphere: Algorithm Nearly Complete, Preliminary Retrievals Underway 13



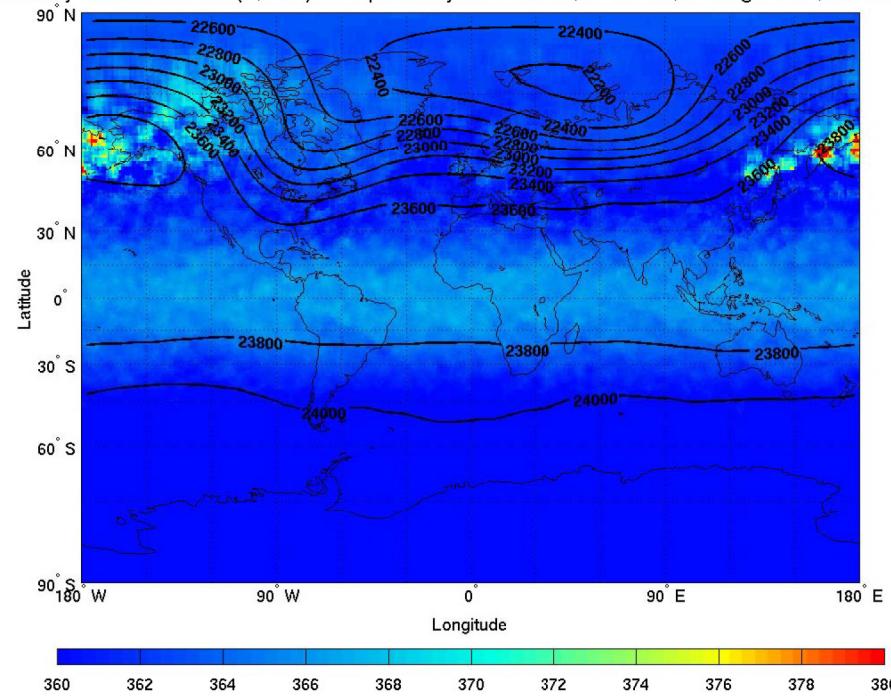
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# Jan 2003 Stratospheric CO<sub>2</sub> Retrieval Compared to Models

(AIRS Stratospheric Contribution Function Applied to Models)

AIRS Retrieved CO<sub>2</sub>

January 2003 Strat CO2 (T,CO2) Clim plus PolyLat Init CO2, smoothed, all cnvgd clust, Iter=2 thru 4



360

Contours are 30 hPa GPH

380

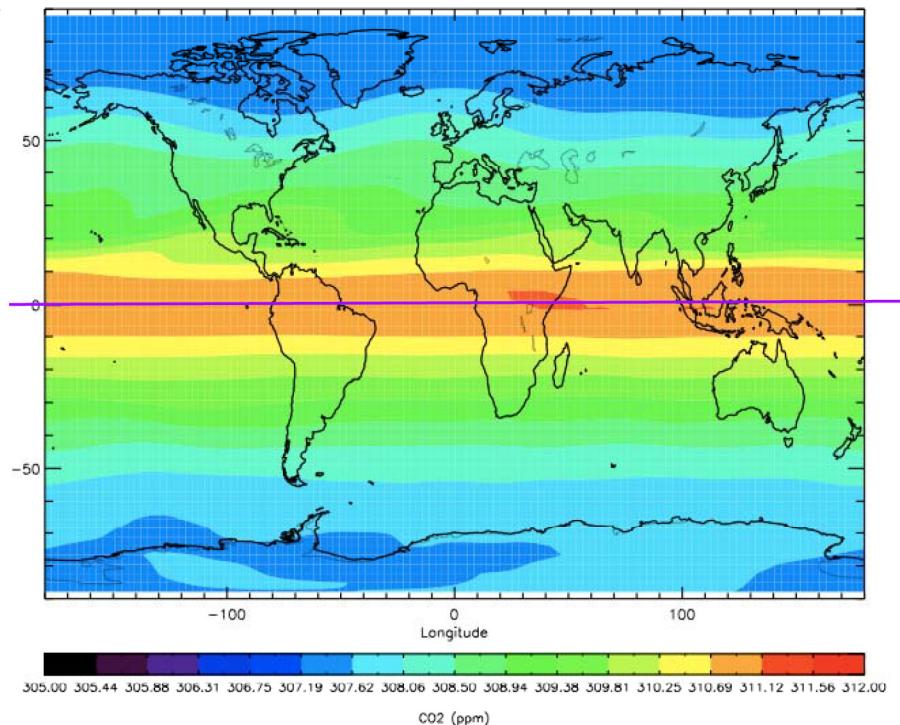
*PRELIMINARY*

Both AIRS and models show presence of tropical pipe

- AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)
- AIRS shows additional troposphere intrusion at high latitude

14

3-D IMATCH CO<sub>2</sub>



305

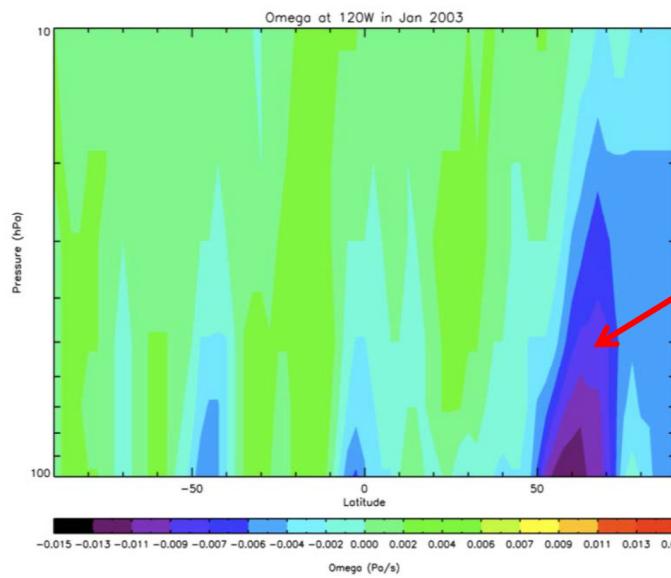
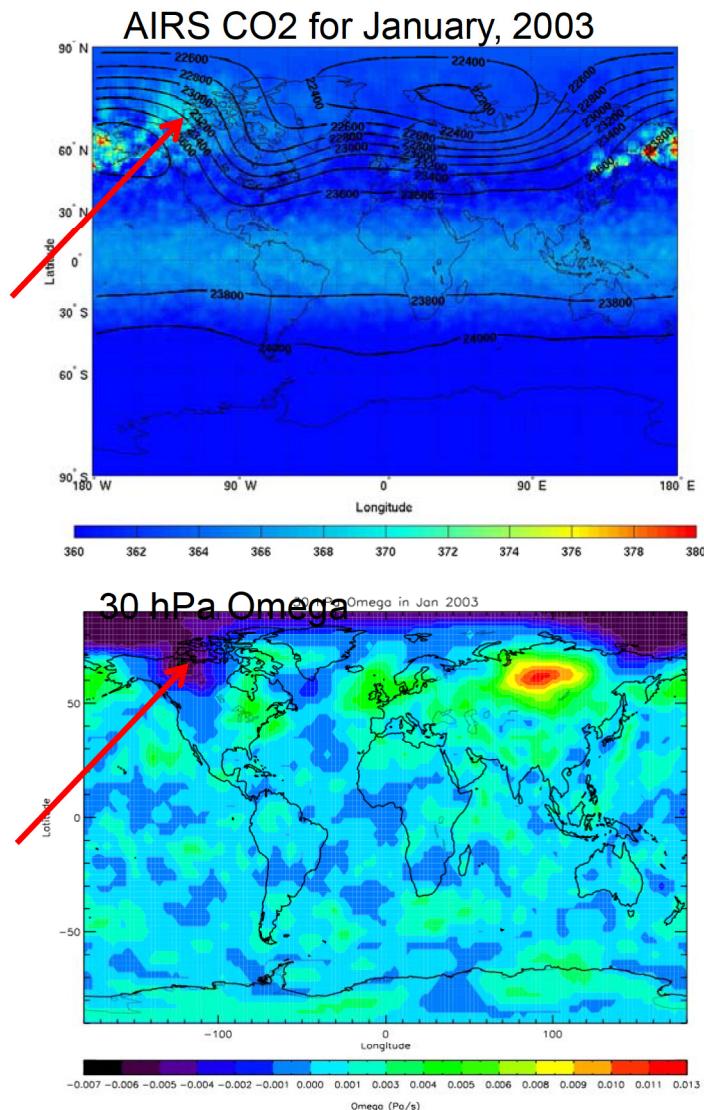
Model profile weighted  
by AIRS sensitivity function

312



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# AIRS Stratospheric CO<sub>2</sub> (tropospheric CO<sub>2</sub> intrusion/vertical wind)



Vertical velocity ( $dP/dt$ ) at 120°W in January 2003 (NCEP2 Reanalysis)

Negative (positive) value represents upward (downward) motion. Units are Pa/s.

Omega =  $dP/dt$  at 30 hPa (NCEP2 Reanalysis)

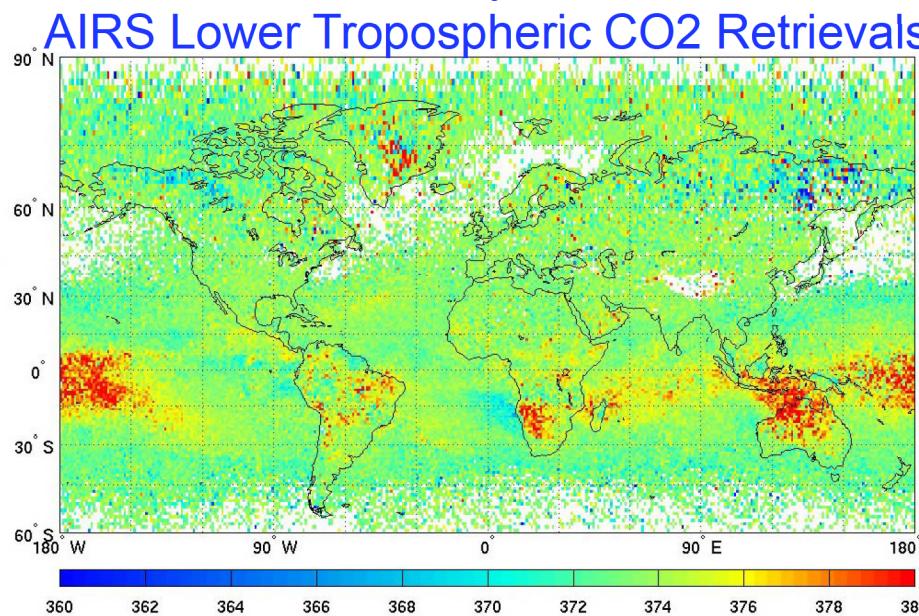
Negative Omega --- Upward motion;  
Positive Omega --- Downward motion



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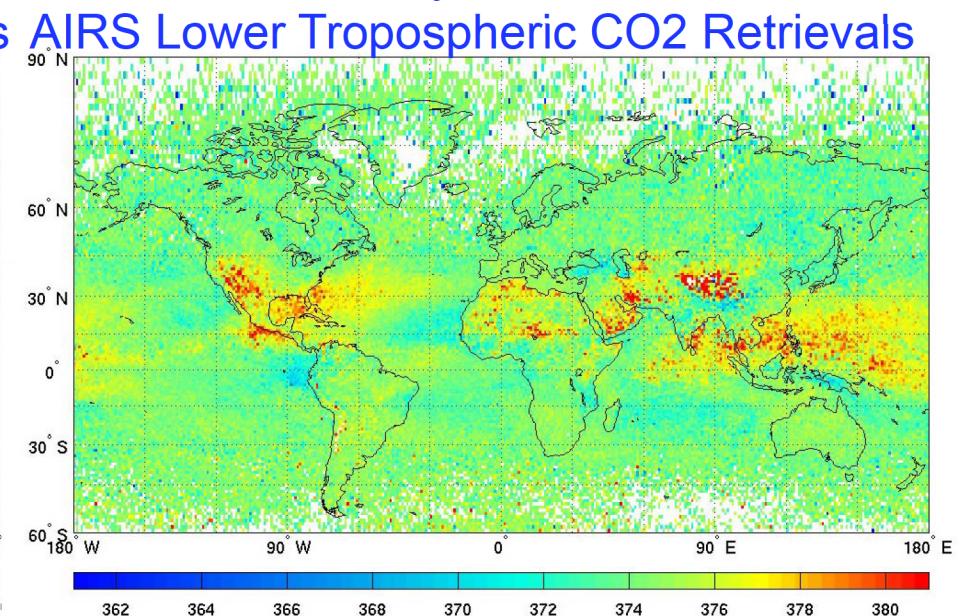
## AIRS Lower-Tropospheric (2.2km) CO<sub>2</sub> (preliminary results – channel set not yet optimized and surface emission module not yet implemented)

January 2003



PRELIMINARY

July 2003



PRELIMINARY





## Summary and Conclusions

- Atmospheric Infrared Sounder
  - Aqua Spacecraft, Launched May 4, 2002
  - Temperature, Water Vapor, Cloud and GHG's
  - Weather, Climate and Composition
- AIRS Mid- Trop CO<sub>2</sub> Validated to be Accurate to Better than 2ppm
- Science Findings
  - Seasonally-Variable Belt of Enhanced CO<sub>2</sub> in the SH
  - Signature of El Nino Seen in CO<sub>2</sub> Product
  - Stratospheric/Tropospheric Exchange of CO<sub>2</sub> as well as O3
  - CO<sub>2</sub> can be used by Modelers as a Tracer for Vertical Transport
- 8 Years of Mid-Trop CO<sub>2</sub> now available
- AIRS Stratospheric and Lower-Tropospheric Products Under Development
- IR Sounders are a key component in the global GHG observing system
- See <http://airs.jpl.nasa.gov>



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## Dr. Mous Chahine (1935-2011)



*A Brilliant Scientist  
A Great Visionary  
A Caring Mentor  
A Good Friend*

Please leave your comments at ...

[http://airs.jpl.nasa.gov/news\\_archive/2011-03-24-Moustafa-Chahine/](http://airs.jpl.nasa.gov/news_archive/2011-03-24-Moustafa-Chahine/)